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ANALYSING THE CONCEPT OF VALUE TO IDENTIFY RELEVANT STAKEHOLDERS' PREFERENCES TO DESIGN FOR ADAPTABILITY

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1. Introduction

Systems are designed to fulfil the needs of their stakeholders. However, those needs or preferences evolve over time due to changes in operational context, market or technology. Systems that are designed adaptably could keep fulfilling the stakeholders' needs and maximize thus the system lifecycle value. Design for Adaptability (DfA) is a "design paradigm that aims at creating designs and products that can be easily adapted for different requirements" [Gu et al. 2009]. The design of a more adaptable system implies modifications in its internal structure (i.e. system architecture). These modifications have a cost that might not be repaid if the adaptations during the life cycle turn on unnecessary. Therefore, more adaptability does not necessary mean more benefit. The quantification of the value of adaptability is a key aspect underlined to be insufficiently addressed and of paramount importance for the design of systems for adaptability and to enable system engineers to choose the right architecture.

The preferences of stakeholders susceptible to change over lifecycle are the source to determine which aspects of the system provide value and should therefore be designed adaptably. However, the identification and assessment of the variable valuable preferences (named as Key Parameters in the paper) is not a trivial matter. First of all, the concept of value should be defined. Value is a subjective term based on stakeholders' perception and depending on boundary conditions [Browning and Honour 2008]. Extensive literature discusses the meaning of the term and its quantification but no consensus has been achieved for the moment and the term remains overdefined and multi-facetted. The magnitude and diversity of definitions is due to multiple dimensions that play into the term value itself. In order to understand the benefits and outreach of adaptability, an understanding of value in the context of engineering systems has to be developed.

This paper represents an analysis on the meaning of the concept of value in order to support a systematic and comparable value assignment of the stakeholders' preferences on technical systems along their life cycle. First, the reasons for the valuation of the relevant stakeholders' preferences to design for adaptability are presented, as well as the nature of the methods that attempt to do it, what leads to the need of improving the understanding of the concept of value and its quantification. Then, an extensive literature research on the different perceptions of value is conducted and summed up in a table, in which value is characterized under different dimensions according to the findings extracted from literature. Subsequently, each dimension and its implications are individually discussed.

2. Motivation

Design for Adaptability (DfA) is a "design paradigm that aims at creating designs and products that can be easily adapted for different requirements" [Gu et al. 2009]. A wide body of literature addresses the advantages that adaptable systems exhibit. [Fricke and Schulz 2005] stress that the three main drivers for system development - *the marketplace*, *the technological evolution* and the *variety of environments* – are becoming more and more dynamic and therefore require system responsiveness. [Browning and Honour 2008] further state that stakeholder needs evolve over time and cannot possibly be perfectly met with a static design. [de Neufville 2003] emphasizes that uncertainty is inevitable and poses both risk and opportunity. [McManus and Hastings 2006] consider adaptability a means of both mitigating the risks as well as exploiting the opportunity. Concluding it can be said that increasingly dynamic environments and contextual factors, longer system lifecycles as well as rapid technological evolution impose the importance of adaptability as a system property.

Adaptability can be implemented in systems modifying their architecture. The architecture of a system is the way to organize its physical components using interfaces in order to fulfil functions [Ulrich 1993]. It defines the technical properties from which the ability of the system to fulfil stakeholders' requirements (derived from their preferences) arises. Thereby system architecture determines the properties of the system either purposely or unknowingly [Kissel et al. 2012]. A modularized architecture allows adding, removing or replacing relevant elements and thus contributes to the ease and extent of adaptations [Engel and Reich 2013]. Since engineers can influence the overall system value only by manipulating the system at physical component level, architectural decisions taken in the early phases of design have significant influence in the system lifecycle performance and therefore in the value provided to stakeholders.

Changes in system architecture in order to increase adaptability imply a cost that may not be repaid if adaptations during life cycle turn on unnecessary. For this reason achieving the right balance between benefits and costs of adaptability is one of the main goals of DfA methods. The existing valuation methods follow the same basic principle: estimation of the value gained with possible adaptations by extrapolating or forecasting the evolution of stakeholders' valuable preferences under uncertainty. From the viewpoint of adaptability only the preferences susceptible to vary over lifecycle are relevant, because they provide the extra value if modified. [Browning and Honour 2008] coin the name of Key Parameters (KPs) to the valuable subjective stakeholders' preferences. According to this definition and from the viewpoint of DfA, this paper refers to KPs as the set of preferences that provide value if they are designed adaptable.

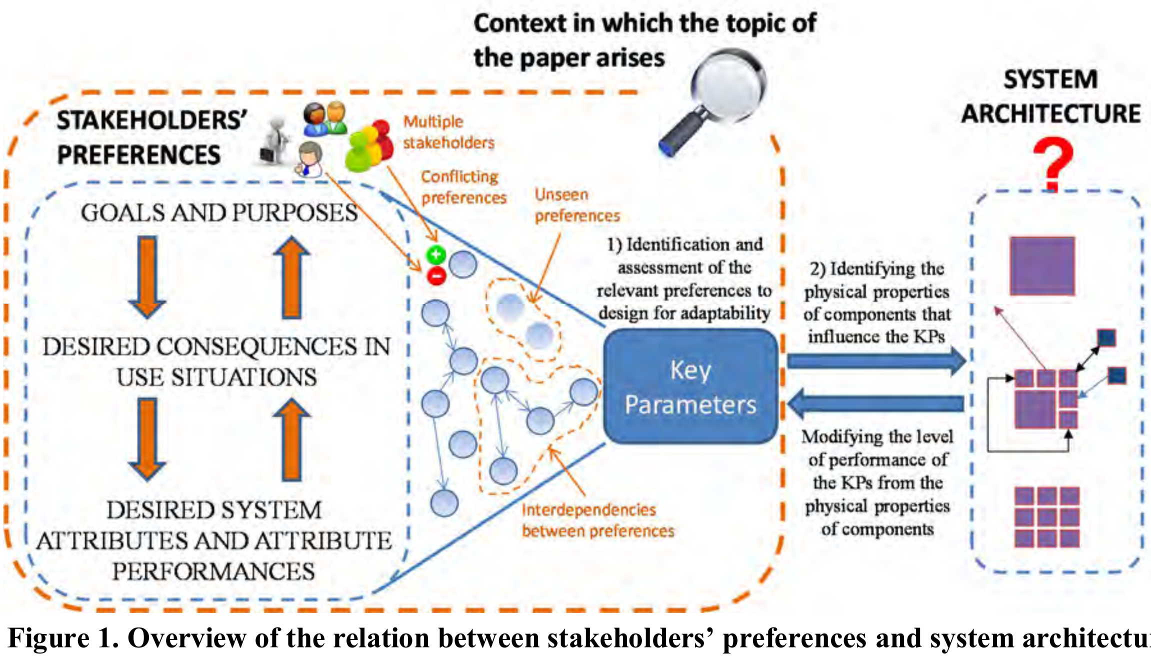

Figure 1. Overview of the relation between stakeholders' preferences and system architecture (stakeholders' preferences based on [Woodruff 1997])

The value of adaptability is determined from the assessment of the evolution of value of the Key Parameters along lifecycle. Thus, not only the identification of the correct KPs must be done but also the quantification of the value that each of them provides to stakeholders. If the KPs are not correctly selected and valuated, the estimation of adaptability value would be misleading. Therefore, the identification and quantification of KPs is of paramount importance for the entire adaptability value assessment and subsequently to decide towards more or less adaptable system architecture. The influence of the general stakeholders' preferences on system architecture via 1) Identification and assessment of Key Parameters and 2) Identification of physical properties of components to derive the system architecture is depicted in Figure 1.

The assessment of KPs is not a trivial matter. First of all, value is a subjective term based on stakeholders' perception and depending on boundary conditions [Browning and Honour 2008]. Extensive literature discusses the meaning of the term and its quantification but no consensus has been achieved for the moment and the term remains overdefined and multi-facetted. Secondly, many aspects make the identification of KPs and quantification of their value a complex problem: multiple stakeholders with different preferences that can be conflicting; diversity in the type of preferences; interdependencies between preferences; unseen valuable preferences; etc.

The topic of the paper at hand arises from in the left part of the Figure 1, that represents the process of identification of the Key Parameters that arise from the stakeholders' preferences and provide value if they are designed adaptable. Regarding the framework presented in Figure 1 and the importance that the identification and assessment of KPs have to understand the benefits and outreach of adaptability, an understanding of value in the context of engineering systems has to be developed. This will be presented in the following section.

3. Value in engineering systems

In order to understand the benefits and outreach of adaptability an perception of value has to be developed. There is no lack of definitions of value in the engineering domain to be found in literature and a common concept is not likely to arise anytime soon. The magnitude and diversity of definitions is due to multiple dimensions that play into the term value itself.

In the marketing literature [Woodruff 1997] provides an overview paper elaborating on customer value, which he distinguishes from personal and organizational value and considers closely linked to a product or service. He describes that the reviewed definitions converge in the point that value is rather perceived by a customers than objectively determined by a seller. Further these perceptions typically involve a trade-off between what the customer receives (e.g., quality, benefits, worth, utilities) and what the customer gives up to acquire and use a product or system (e.g., price, sacrifices. Whether benefits and costs are treated as a sum (benefit – cost) or a ratio (benefit/cost) is not elaborated on and remains a significant open question treated differently or not at all in different references.

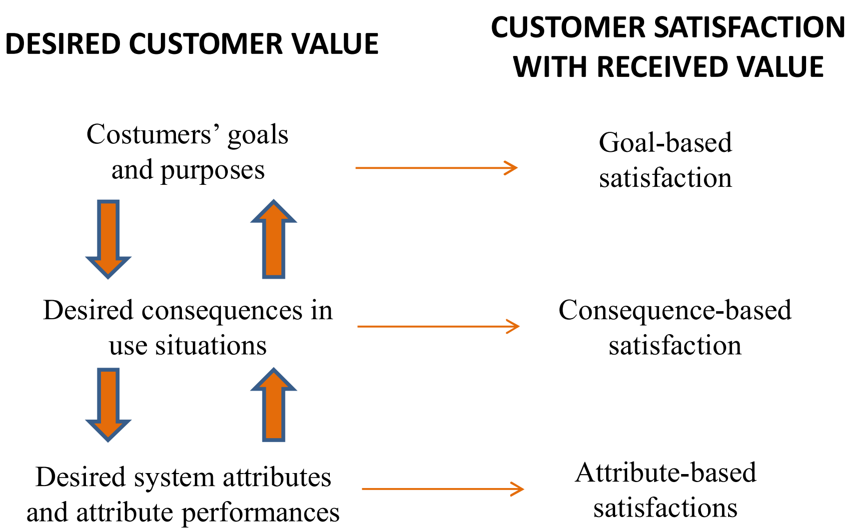

Figure 2. Customer Value Hierarchy Model comp [Woodruff 1997, p. 142]

[Woodruff 1997, p. 141] further states that customer value concepts diverge in futher details and reveals substantive meaning differences. As one of those differences he names the way the definitions are constructed, typically relying on other terms, such as utility, worth, benefits, quality or emotional bond that, too often, are themselves not well defined and makes it difficult to compare concepts. In order to systematize on which levels customers perceive value [Woodruff 1997, p. 142] introduces a value hierarchy (see Figure 2), suggesting that customers conceive of desired value in a means-end way and it would be more beneficial to reverse the process for a company during product generation.
[Woodruff 1997, p. 142] conclude by proposing a definition: Customer value is a customer's perceived preference for and evaluation of product attributes, attribute performances, and consequences arising from use that facilitate achieving the customer's goals and purposes in use situations.
The marketing literature provides further insights on what customers and markets value and prefer. [Mello 2002] provides guidelines for customer-centric product development. [Slywotsky 1996] notes how value evolves in terms of customers' priorities, time horizons, willingness and ability to pay, etc. and concludes that products and services should be adapted to take advantage of and minimize the risks of these changes. However, in reviewing stakeholder theory at this level, [Rebentisch et al. 2005] conclude that "past research provides no clear-cut guidance on a process to identify and assess stakeholders and their needs over time.
[Browning and Honour 2008] acknowledge that the customer is the most important stakeholder of a system but argue that further stakeholder need to be taken into account. They state that the value provided by a system, let alone its *lifecycle value* (LCV), is difficult to quantify for reasons of largely subjective perception of value, difficulty in articulation and conflicting opinions on the individual as well as group level as soon as several stakeholders are involved. In terms of a lifecycle perspective it is further not just of importance what will satisfy stakeholders today but in the future, determined also by alternative solutions to evolving stakeholder needs and wants.
[Pozar and Cook 1998] demonstrate how to measure the relative value of an automobile design as a function of one of its attributes (vehicle interior noise). The issue of non-linear contribution of certain system attributes to the overall system perceived value is treated by research around the term utility. A classic concept is presented by [Kano et al. 1984], differentiating delight, performance and basic attributes. [Browning et al. 2002, p. 446] state that besides attributes that can be defined as *smaller is better* (SIB) or *larger is better* (LIB) furthermore nominal is best (NIB) attributes exist that are optimal at a certain nominal point.
Approaches on how to treat multiple attributes and their interdepence are addressed in decision making [Keeney 1993] and multi tradespace exploration (MATE) [Ross and Hastings 2005, p. 4]. In latter attributes that reflect objectives of a decision maker are converted into an aggregated measure via value functions. The so called utility for different solutions is then mapped against their respective cost. Advanced approaches also consider changing decision maker preferences and their influence on the mapping of alternatives.
[Browning and Honour 2008] provide an approach for the measurement of lifecycle value based on the perceived value of a system in the eyes of its stakeholders. This perceived value, which changes across stakeholders and across time, can be quantified in relation to a set of key parameters (KPs). The value varies between 0.0 and 1.0 (no vs. complete stakeholder satisfaction) and is assessed in time intervals (e.g. years), whereas the sum of the stakeholder value over the years is assumed to reflect the Lifecycle Value of the system.
For lifecycle assessment approaches out of the field of economics such as *Average Net Present Value* (ENPV) Calculation or *Real Option Analysis* (ROA) seek ways to measure flexibility in monetary terms, where possible based on discounted cash flows of a system. (e.g., [Banerjee and de Weck 2004], [Silver and de Weck 2007], [de Weck et al. 2004], [Kalligeros and de Weck 2004], [Kalligeros 2004], [Suh et al. 2007], [de Neufville and Scholtes 2011]).
The Table 1 sums up the dimensions of value in engineering systems and its characteristics discussed in this section. It is to be read like a morphological box, well established in product development [Zwicky 1966]. To define a concept of value each dimension needs to be assigned one of the possible enumerated characteristics listed behind it. In order to structure the multitude of dimensions those are clustered in five categories. A category represents the final purpose of a group of dimensions. Thus,

the category "value perception" comprises the dimensions that support the global understanding of the sources of value (one or multiple, gain: e.g. functionality, sacrifice: e.g. additional cost) for the correspondent person. The category "value assessment" attempts to quantify the value abstractly defined in the category "value perception". The category "value combination" plays a role in case of multiple sources of value. In this category are included the dimensions that support obtaining the value resultant of the combination of multiple individual values. The category "lifecycle considerations" comprises dimensions that define how value might change over time. The category "uncertainty management" finally addresses the uncertainties existent in the other dimensions and the awareness of value sources. A concept of value can tendentially be interpreted as more sophisticated the further right the applied characteristic of each dimension is and the more characteristics towards the bottom of the table are considered. Therefore, once the characteristics for a specific case are chosen, the characteristics left in the right part of the table do not have to be considered anymore since the case does not require this level of complexity.
The Table 1 presents a colour code that indicates which elements that play a role depending on the dimension preference. The red elements are to be applied for understanding of isolated value of individual preferences, whereas the green elements must be considered only in case of multiple preferences. The blue elements must be always taken into consideration.

Table 1. Dimensions of Value in Engineering Systems

CATEGORY	DIMENSION	POSSIBLE CHARACTERISTIC			
Value perception	Preference	One	Multiple		
	Subject	Customer	Stakeholder		
	Gain (G)	Goal	Consequence	Attribute	
	Sacrifice (S)	Goal	Consequence	Attribute	
	Metric	Qualitative	Quantitative	Monetary	
Value assessment	Operation	Ranking	Difference (G-S)	Ratio (G/S)	
	Monetary Conversion	None	Direct (Ratio attribute/$)	Cost savings	Via market shares, sales, …
Value combination (*only in case of multiple preferences)	Interdependencies	No	Constant	Variable	
	Aggregation	Sum	Weighted Sum	Function (Kano, Utility, …)	
Lifecycle considerations	Variability over time	No	One Dimension	Multiple Dimensions	All Dimensions
	Aggregation over time	None	Average	Cumulation	
Uncertainty management	Uncertainty	No	One Dimension	Multiple Dimensions	All Dimensions
	Awareness of value sources	Known	Partially Known	Unknown	

4. Analysis of the dimensions of value

The Table 1 of dimensions of value in engineering systems supports the systematic characterization of value. A dimension represents a characteristic of value that must be discussed for every specific case. This section covers the table from top to bottom explaining the meaning of each individual dimension and suggesting methods to characterize the dimension. The characterization is exemplarily applied to two stakeholders' preferences of a transportation system. The aforementioned system operates on a manufacture plant and transports automobile's parts between different machines in the plant during the manufacturing process.

4.1 Value perception

This category comprises the dimensions that support the global understanding of the sources of value.

4.1.1 Preference

The dimension preference represents the desires of stakeholders, i.e. the number of "gains" that they consider. There can be just one aspect providing the perceived value or multiple aspects. Regarding the case of the transportation system, multiple preferences of stakeholders are perceived as valuable if they could be provided by the system. Two of them are taken as example to illustrate the application of the Table 1: more functionality of the system and higher transportation speed.

First, the individual value perception of every preference isolated is characterized but the existence of more than one preference leads irretrievably to the need of consideration of the resultant value of both preferences. This is considered in the category "value combination". In case of existence of one preference, the category "value combination" (green category) can be neglected.

4.1.2 Subject

The subject represents individuals or groups with a vested interest in a system. They are the ones who receive the gains from the system and sacrifice something in exchange. The importance of the customer is vastly reflected in literature but the rest of stakeholders are also relevant if they exist and they have to be identified and prioritized in order to obtain their preferences to select towards the Key Parameters. [Browning and Honour 2008] propose methods for the identification like brainstorming, market analysis, operation analysis, workflow analysis, and supply and value chain analysis.

In the example of the transportation system, the two selected preferences were stated by the customer. Other stakeholders were also identified but their preferences are not shown in this paper.

4.1.3 Gain

Stakeholders gain value from some properties that the system offers to them. The consideration of value is subjective, emanates from individuals and depends on the boundary conditions. That leads to different considerations of the valuable properties of the same system. [Browning and Honour 2008] point that the identification of preferences requires working close to the stakeholders and listen to them, using methods such as brainstorming, group discussion, surveys, ontologies and templates.

The properties that provide benefits to stakeholders are perceived in three levels of hierarchy: goals, consequences, attributes (Figure 2). [Browning and Honour 2008] explain that stakeholder preferences are usually operational (consequences) because stakeholders think in terms of operational results more that in terms of technical implementations (attributes). Depending on previous experiences or technical knowledge they can also point general goals or very specific technical attributes.

KPs could be theoretically at any level, so that the allocation of the preferences in the three levels and the recognition of the correspondent relations are key to identify in which level is exactly the value and avoid thus repetitions or/and over/underestimations towards the selection of the KPs. KPs should be as general as possible to capture the essence of the stakeholder desire but as specific as needed to understand the stakeholder’s desire. The selection of the appropriate KP for each case requires an extensive reflection.

In the case of the transportation system the preference "I want higher transportation speed" can be seen as a consequence that has the goal "I want to increase the production". Attributes were not considered since the initial preference was expressed as a consequence and thus the search for the KP continues on the left side on the Table 1. "Higher transportation speed" is considered in this case the KP because it is the main consequence that leads to this goal. "I want a more functional system" is considered as a goal and directly a KP.

4.1.4 Sacrifice

The sacrifices are the things that stakeholders "give up, compromise on, have to live with, are disappointed with, or have to pay for as a result of the system’s development and existence" [Browning and Honour 2008]. A classic example of sacrifice for a customer is the price that he has to

pay for the system. Sacrifices have the same subjective condition as the gains and also the same conceptual hierarchy. Therefore, they are identified using the same methods as the gains and they also present the same challenges to be delimited.
In the exemplarily preferences the sacrifices are the costs of obtaining more functionality of higher speed for the transportation system.

4.1.5 Metric

The value provided by the properties can be assessed qualitatively, quantitatively and in monetary terms. Human perception is usually qualitatively expressed in terms like "low value", "considerable value", "high value", etc. with undefined boundaries [Bojadziev and Bojadziev 1995]. Each stakeholder has his own operational language [Browning and Honour 2008], what makes significantly opaque the quantification of the individual value.
The perceived value can be quantified using scales like for example [Browning and Honour 2008] do quantifying from 0.0 to 1.0 (no vs. complete stakeholder satisfaction). The quantification in monetary terms is rarely directly provided for the stakeholder. The need of quantification in monetary terms and how to do it are addressed in the section 4.2.2.
In the examples the benefits of increasing functionality of the transportation system can only be qualitatively perceived. Increasing the speed of transportation can be quantitative perceived by calculating the extra amount of parts that can be produced by increasing the speed.

4.2 Value Assessment

It comprises dimensions that attempt to quantify the value abstractly defined in the previous category.

4.2.1 Operation

The operation represents the most suitable trade-off to obtain the intrinsic value. The most suitable operation depends on the case and considerably on the available metric. It can be a ranking, the difference between gain and sacrifice, or the ratio between the gain and sacrifice.
In the preference "more functionality" exposed as example, the operation to assess the value corresponds to the ratio functionality/cost because it is a strategic preference, a characteristic in continued improvement but not to really obtain benefits. Regarding the preference "higher speed", the operation G-S seems the appropriate one, because the value is focused in the increase of production and thus the value lies in the benefits that it generates.

4.2.2 Monetary conversion

Value should be measured in the same terms to allow the easy comparison between the different preferences. Regarding the overall assessment of adaptability, the ultimate goal is to compare its benefits (arising from KPs value evolution and the ability of the system to provide them during lifecycle) with its costs (relative easy to calculate arising from the modifications in system architecture). Costs are expressed in monetary terms and so should be the benefits to facilitate the comparison. The translation into monetary terms of abstract preferences presents a challenge. The conversion can be direct (ratio attribute/€), represented in form of cost savings or via market share and sales calculation. These ways of conversion imply a return of investment on time that is not obvious to quantify. Approaches like Real Options Analysis (ROI) or Expected Next Present Value (ENPV) present methods to obtain a monetary valuation of the preferences.
In the two preferences exposed as examples, the monetary conversion can be done via calculation of market shares, sales, etc. The assessment must be conducted in collaboration with the company and market experts that contribute with their experience.

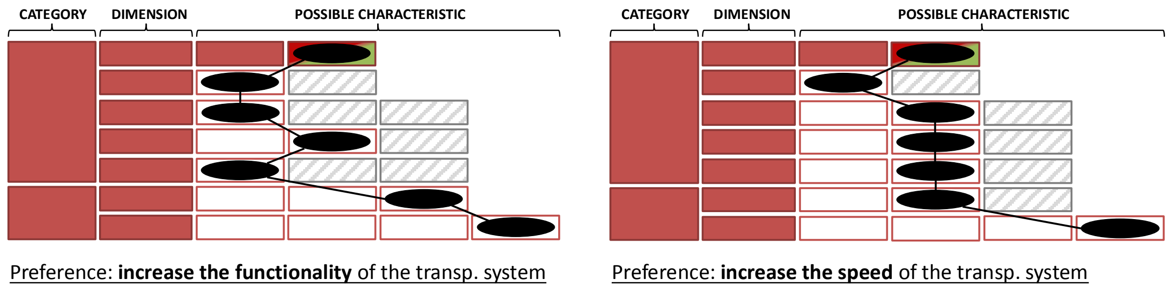

Figure 3. Characterization of value perception and assessment for two individual preferences (check correspondent text in Table 1.)

4.3 Value combination

This category is relevant only in case of multiple sources of value. Here are included the dimensions that support obtaining the value resultant of the combination of multiple individual values.

4.3.1 Interdependencies

Stakeholder preferences can be related between them both in the same hierarchical level as well as in between the different value levels (see hierarchy in Figure 2). Furthermore, these interdependencies can occur between the preferences of one stakeholder but also between the different stakeholders. Furthermore, the interdependencies can remain constant during lifecycle or vary over time.
These relations increase considerably the complexity of the problem of identifying the reliable source of value. The more complex the network of stakeholders is, the more complex are the dependencies between their preferences. Furthermore, stakeholders can point conflicting preferences that represent a compromise towards the assignment of the global value that those have. The problem can be even more complex if the dependencies are dynamic. Typical methods of complexity management like Design Structure Management (DSM) to understand dependencies between the same levels and Multi Domain Matrix (MDM) could be applied to clarify the dependencies between levels.
In the example the preferences "more functionality" and "higher speed" a relation between the two preferences exists, since both refer to the operating ability of the system. The relation is considered variable to illustrate the example, but it has not been yet evaluated with the methods mentioned above.

4.3.2 Aggregation

The aggregation is the way in which the value assigned to the different preferences is combined to reveal which is the overall value of the set of preferences. In the simplest case, the overall value is the direct sum of the values of the preferences. In this case the preferences do not have any kind of dependency between them and all of them contribute with their total value to the overall one. In cases with dependencies the value of multiple preferences should be combined into a single index. There are many mathematical methods used to do it and according to [Browning and Honour 2008] the most common one is the weighted sum. More sophisticated methods like Kano Model [Kano et al. 1984] or Utility Function [Browning and Honour 2008] can help to interpret stakeholders' opinions and identify the effective meaning of stakeholders' preferences in terms of value.
In the case of the example a weighted sum seems an appropriate option since both preferences provide value due to market share and sales.

4.4 Lifecycle considerations

This category comprises dimensions that define how value for stakeholders might change over time.

4.4.1 Variability over time

The preferences of stakeholders can vary over system lifecycle. They can vary in one dimension or change in multiple dimensions. In the most complex case, all dimensions are susceptible to change during lifecycle.

Typical methods to predict value changes in the future (interviews, surveys, etc to customers) are not very effective, since customers are biased by their current preferences and thus not able to recognize many future needs [Woodruff 1997]. Indirect approaches based on multiple data sources could be more effective in the predictions. Those approaches could combine a search for past patterns of change in different levels of the hierarchy of preferences with the consideration change-influent factors like macroenvironmental forces, competitors' innovations, emergence of new markets, and changing customer use situations. An example of this kind of analysis was conducted by [Chen 2012], who investigates customer preferences by combining passive analysis of past data with active collection of preferences with interviews.
In the considered examples, multiple dimensions are susceptible to vary, like the preferences themselves, which could not be considered anymore as value adders because at some point the expectations of the company are fulfilled.

4.4.2 Aggregation over time

Value can be generated over time, for example in of a seller that is receiving constantly benefits due to sales. If the value over time is generated, it can be quantified as the average along time or the sum of the total. The way of obtaining the final value achieved in these cases depends (like in the dimension of operation) on the specific case and considerably on the metric.
For the example the considered value over time is the sum of the value gained during all the years that the "higher speed" and "more functionality" are contributing to increase benefits (cumulation).

4.5 Uncertainty Management

It comprises the uncertainties existent in the other dimensions and the awareness of value sources.

4.5.1 Uncertainty

The uncertainty regarding the identification and assessment of the dimensions must be considered. The more dimensions are considered under uncertainty, the more accurate the valuation would be. The representation of value in form of probability distributions would be more realistic than trying to get a single number. Methods like Monte Carlo Simulation or Sensitivity Analysis can be applied to consider the uncertainties and understand how they influence in the final assessment.

4.5.2 Awareness

The identification of the stakeholders' preferences mostly follows the "intuitive strategy" based on knowledge and previous experience acquired by education or practice, especially on the correction of previous mistakes [Hosnedl et al. 2004]. That leads in most of the cases to the omission of relevant properties (unknown value) that are unseen or "covered" by others that seem very attractive but in fact are less important [Kano et al. 1984]. The omission of valuable preferences would probably lead to a wrong selection of the KPs and thus to a misleading calculation of the value of adaptability.

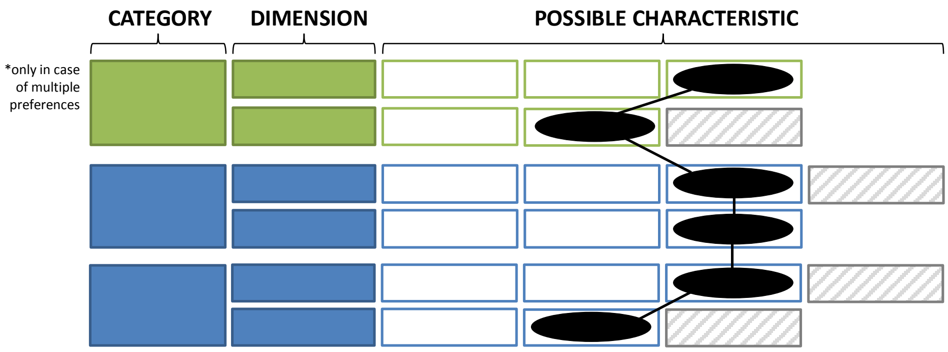

Figure 4. Characterization of value combined and general value for two preferences (check correspondent text in Table 1.)

In most of the cases the situation is the partially awareness (partially known) of the valuable preferences. [Hosnedl et al. 2004] propose the identification of these unseen stakeholder preferences by regarding general classifications of systems properties that support the selection of preferences in order to be aware of all the possible ones. They present a systemic strategy using systemic graphical models and including the existing knowledge about physical properties. Other methods like use-case scenario or Delphi method could also be applied to bring the hidden preferences out.

5. Conclusion and further work

This paper underlines the importance of the identification and assessment of the valuable preferences of system stakeholders (Key Parameters) to design for adaptability. In order to identify and assess those KPs, an understanding on the concept of value in engineering systems was developed. The concept of value was structured and characterized in several dimensions with their characteristics. This classification supports the systematic characterization of value. Its application to valuate stakeholders' preferences assures the consideration of all the dimensions and thus provides a consistent and comparable value understanding. The characterization in dimensions constitutes the basis to realize a more specific assessment (both in every dimension and holistically) that can be conducted using mathematical techniques in combination with forecasting methods. Some methods for specific assessment in every dimension are pointed out as possibilities for further research to improve the accuracy of the values. This valuation would contribute to achieve the final objective, identification and assessment of the Key Parameters in order to obtain the value of adaptability.

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